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[redacted] FROM WHICH THE BOUNDARY LAYER

[redacted]D BY SUCTION

[redacted] Betz and O. Schrenk

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

TECHNICAL MEMORANDUM NO. 374.

EXPERIMENTS WITH AN AIRFOIL FROM WHICH THE BOUNDARY LAYER IS REMOVED BY SUCTION.*

By J. Ackeret, A. Betz and O. Schrenk.

Our attempts to improve the properties of airfoils by removing the boundary layer by suction, go back to 1922. This principle was involved in Professor Prandtl's experiments in 1904, but, so far as we know, no successful application of the suction method to technical problems has yet been made. The object of the suction is chiefly to prevent the detachment of the boundary layer from the surface of the airfoil. At large angles of attack, such detachment prevents the attainment of the great lift promised by the theory, besides greatly increasing the drag, especially of thick airfoils. Omitting many intermediate experiments, we will give a few recent results. The experiments were rendered financially possible by the Flettner and Daimler companies.

The airfoil tested (F.A.41) was mounted in the small wind tunnel of the Institute, so that one end was secured to a side wall and the other end projected into the air stream. This arrangement was necessary, in order to provide for the suction of

*"Versuche an einem Flügel mit Grenzschichtabsaugung" from "Vorläufige Mitteilungen der Aerodynamischen Versuchsanstalt zu Göttingen, No. 4.

the air through the inside of the airfoil and out at one end. It rendered impossible, however, the usual method of power determination by weighing, for which pressure-distribution measurements had to be substituted.

The object of the experiments was to produce a good adherence of the boundary layer to the airfoil with the minimum suction force. We measured the requisite quantities Q and the negative pressures p produced by the suction. The suction force (without taking account of the pump efficiency) was then

$$L = Qp = z \frac{\rho}{2} v^3 F,$$

in which ρ is the air density; v, the wind velocity; F the airfoil area (chord × span); and z, a nondimensional coefficient denoting the power. The latter is exactly comparable with the drag coefficients c_{wi} and c_{wo} of a wing.

The airfoil had a thick Joukowski profile (Fig. 3). The suction was applied only to the top of the wing and only through the three separate chambers shown in Fig. 3, since it was impracticable to employ on the trailing edge the relatively great negative pressure required near the leading edge.

Figs. 1-2 show the arrangement in detail. For measuring the pressure, there were three tubes at each end of the airfoil, the ones at the left being shown in the photograph (Fig. 1). For measuring the quantity three measuring nozzles were inserted in the three suction pipes. Three throttle valves were also provided for regulating the quantity and pressure in the separate chambers. In Fig. 1, the suction sieve is partially covered (with pasted thin black paper), since it was found that, with certain coverings, only a small suction force was needed to prevent the detachment. The four white threads in the air stream (Fig. 1) show the deflection of the air current by the airfoil.

The above-mentioned pressure-distribution measurements could not be made in the usual manner, by means of measuring holes from the inside of the airfoil, but by means of a pressure gauge (Sonde) placed on the surface (error ±5%). Thus the normal pressures along the airfoil surface were obtained and the resulting force (coefficient c_r) could be calculated, which comprises most of the lift and induced drag, but not the tangential forces produced by the skin friction, which constitute the principal part of the profile drag. We give two results obtained with suitable coverings:

c_r =	2.95	3.6
z =	0.03	0.12
α =	17.5°	28 (computed for infinite aspect ratio)

The angle of attack α was measured, as usual, with reference to the chord. Greater c_r values (5-6) could be obtained by increasing the suction force to a multiple.

The profile drag was also determined for moderate values of c_r by the impulse method ("Zeitschrift für Flugtechnik und Motorluftschiffahrt" 1925, p.42). The reduction in the profile drag by suction is shown to a certain extent by Fig. 4. The total pressure g along a straight line perpendicular to the chord, 7 cm (2.76 in.) behind the trailing edge of the airfoil (i.e., the total energy at every point across the stream) was measured and expressed in its ratio to the undisturbed total energy g_o of the flow. The ratio g/g_o has values smaller than 1 in the region which is filled with the flow coming from the boundary layers of the airfoil. It can be demonstrated that the areas between the straight lines $g/g_o = 1$ and the curves are proportional to the profile drags, up to an error whose upper limit can be estimated. In our cases, the necessary corrections always remain under 10%. In Fig. 4, four such measurements are plotted, of which curve 1 was obtained with the strongest, curve 3 with the weakest, and curve 4 without suction, and indeed with $\alpha = 4°$ and $c_r = 1.2$. For $c_r = 0.9$ in one case we obtained:

Profile drag without suction,	c_{wo}	$= 0.029$,
" " with "	c_{wo}'	$= 0.014$,
Requisite suction force	z	$= 0.007$
	$c_{wo}' + z$	$= 0.021$

Translation by Dwight M. Miner,
National Advisory Committee
for Aeronautics.

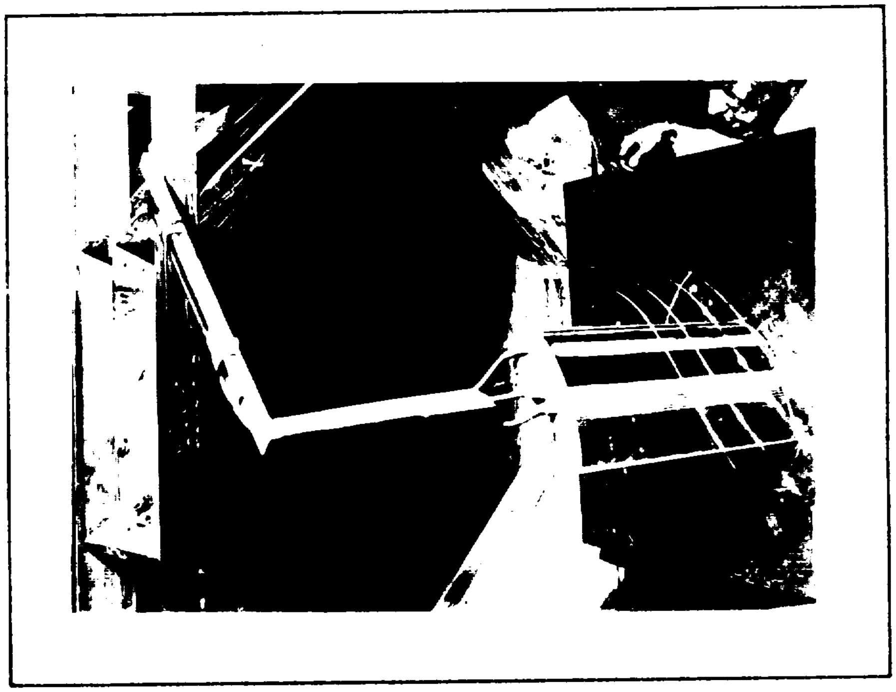

Fig. 1

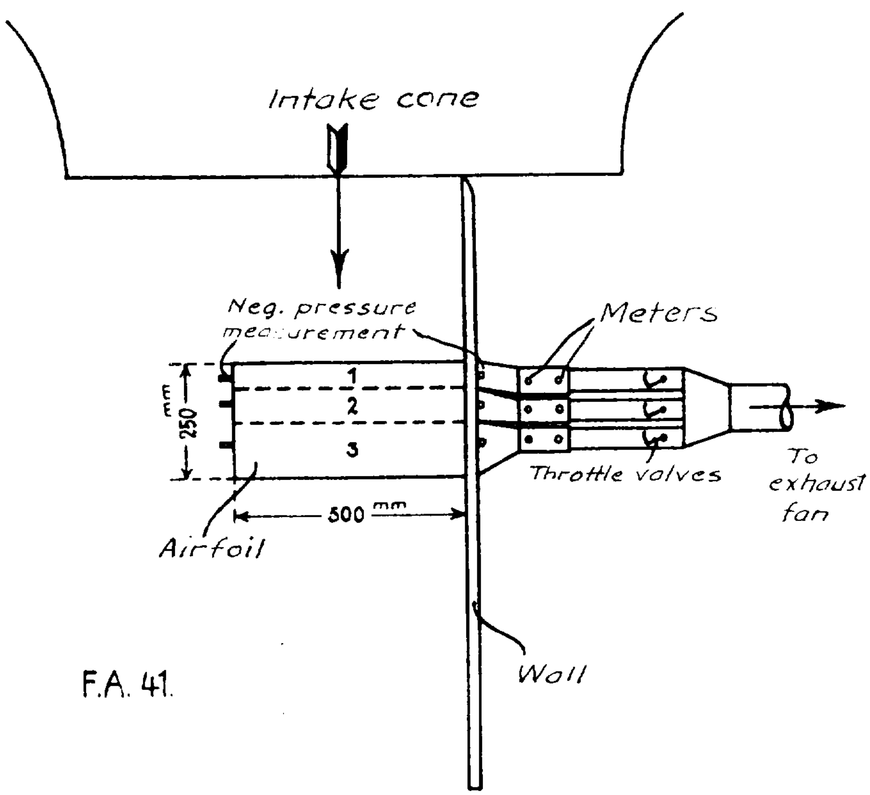

Fig. 2

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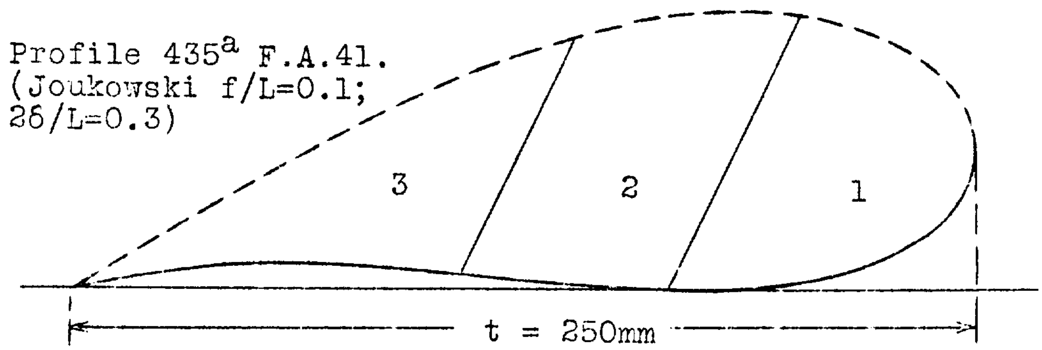

Fig.3 Profile showing division into compartments.

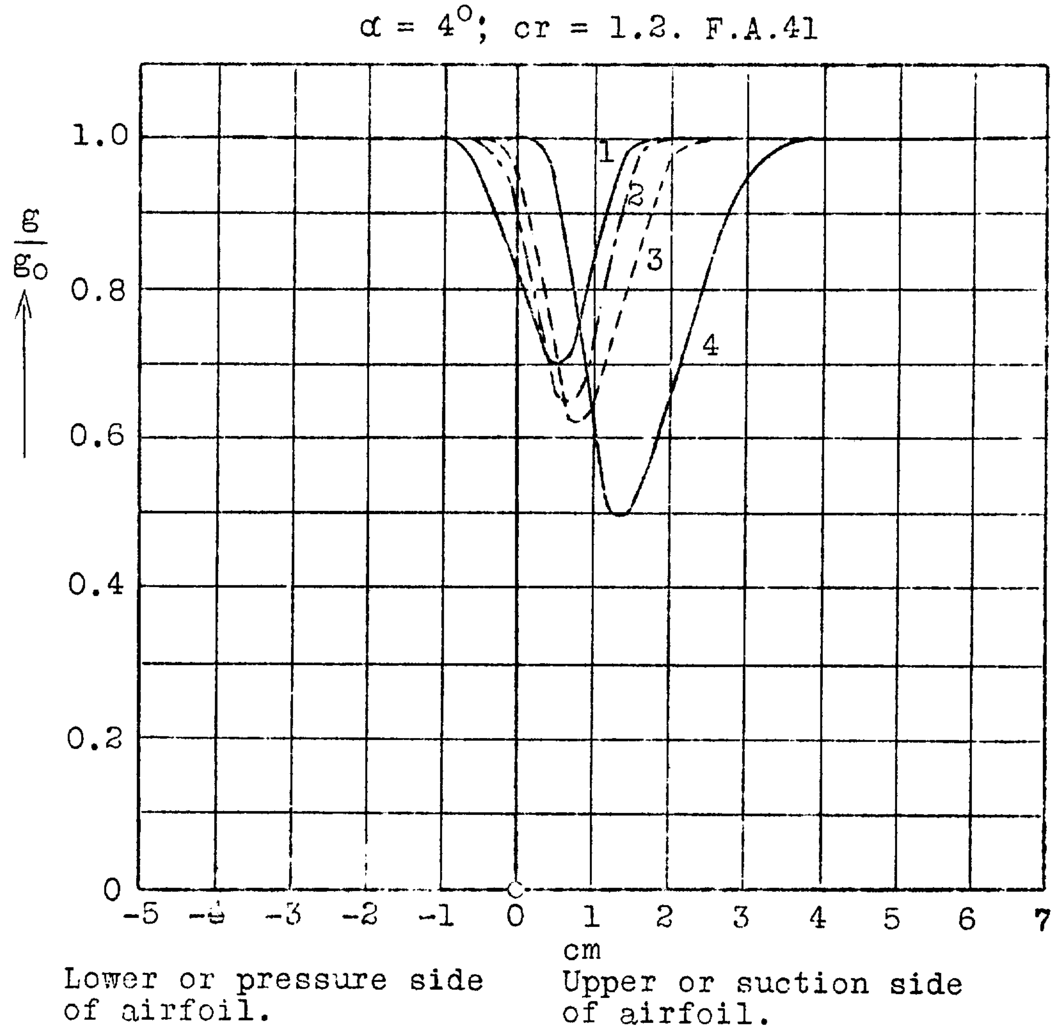

Fig.4 Reduction of profile drag by suction.